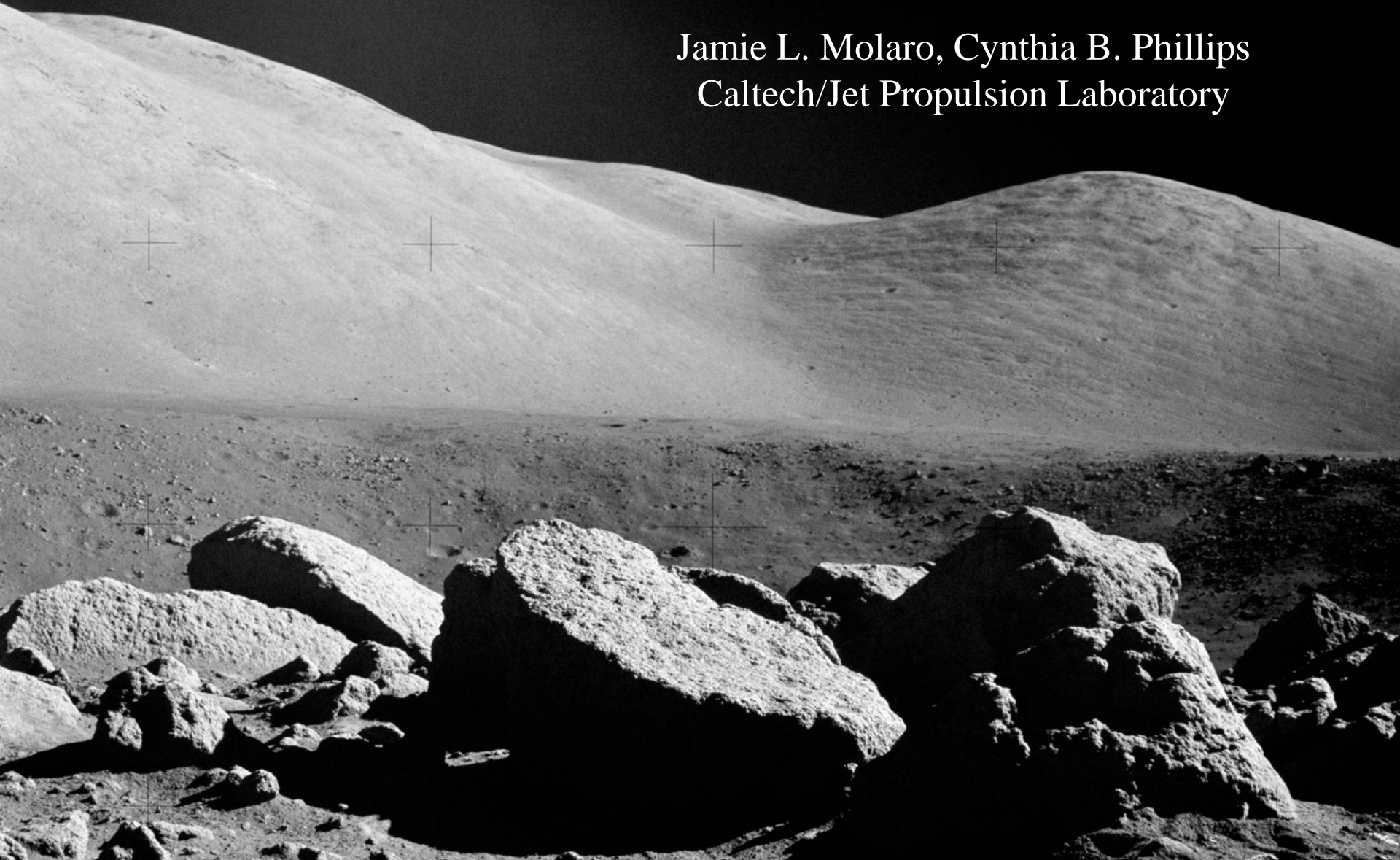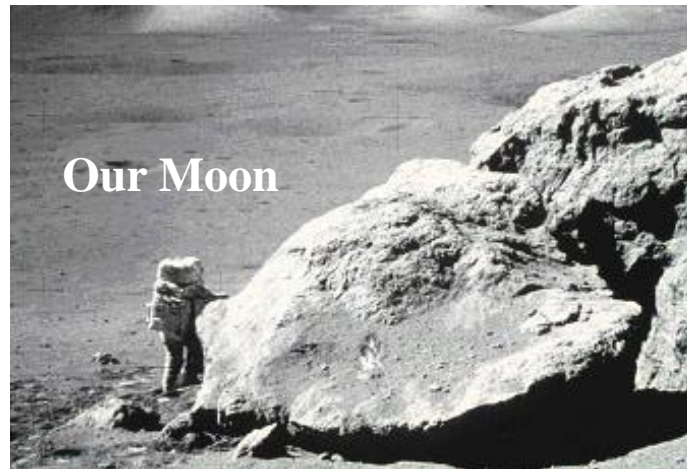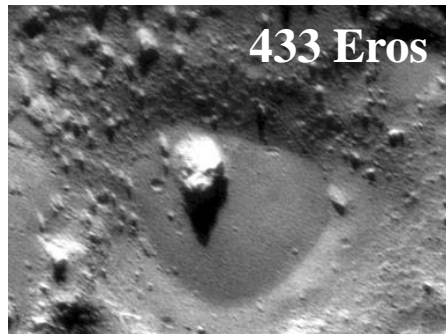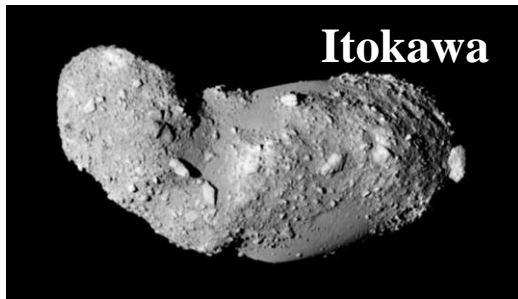# Thermomechanical behavior of ice and ice-rock mixtures at the mineral grain scale

Jamie L. Molaro, Cynthia B. Phillips
Caltech/Jet Propulsion Laboratory

Thermally Induced Rock Breakdown

Breakdown of material from diurnal, thermally induced stress caused by expansion and contraction of material.
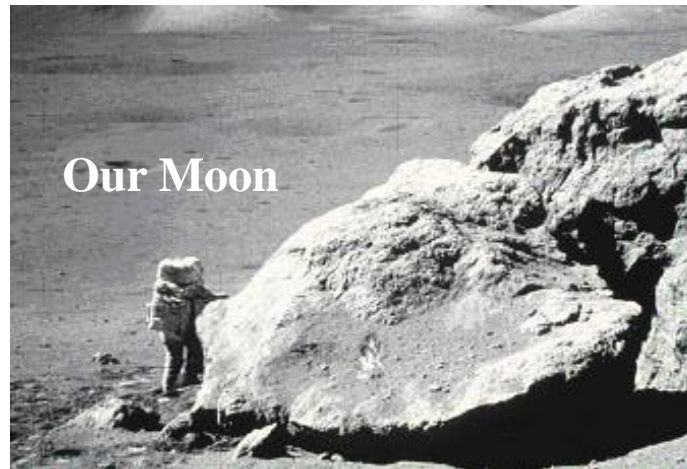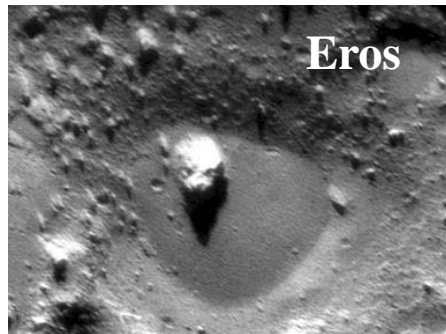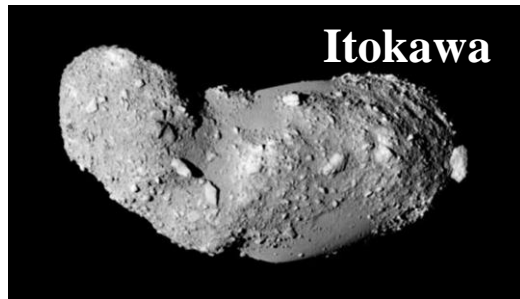

Itokawa

433 Eros

Our Moon

Thermal fatigue and shock may contribute to:
- exfoliation
- crack formation
- granular disintegration
- contributions to other processes

Thermally Induced Rock Breakdown

Breakdown of material from diurnal, thermally induced stress caused by expansion and contraction of material.
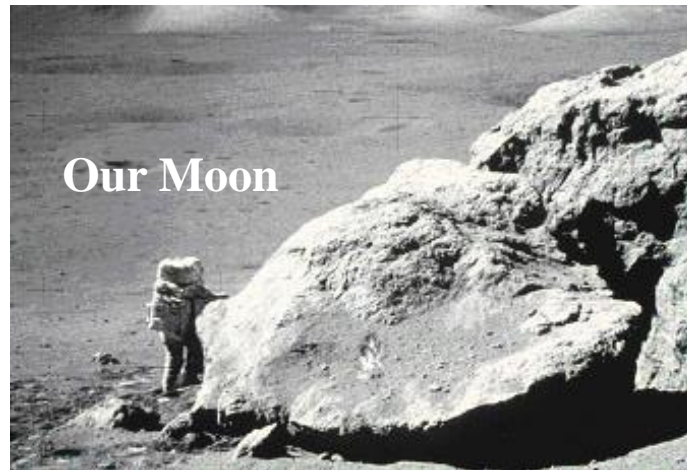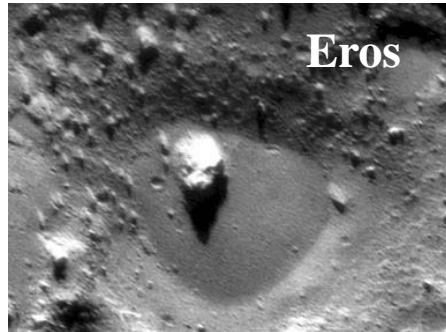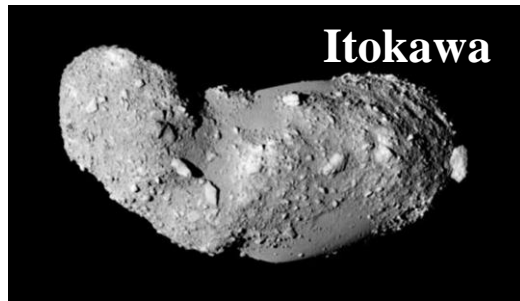
Itokawa

Eros

Our Moon

$$\sigma \propto \Delta T$$

- Airless bodies
- Slow rotators
- Small solar distance
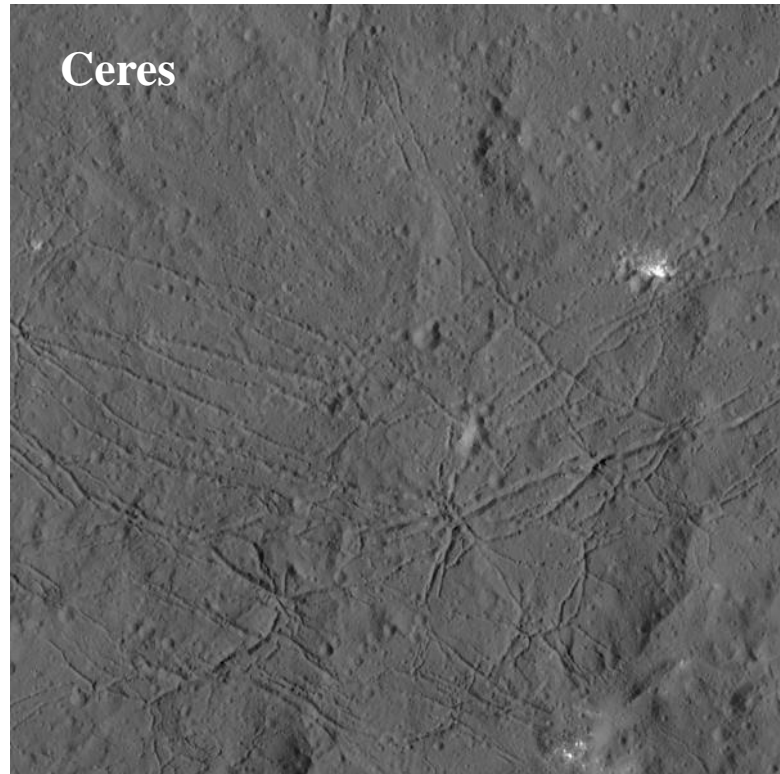
Thermally Induced Rock Breakdown
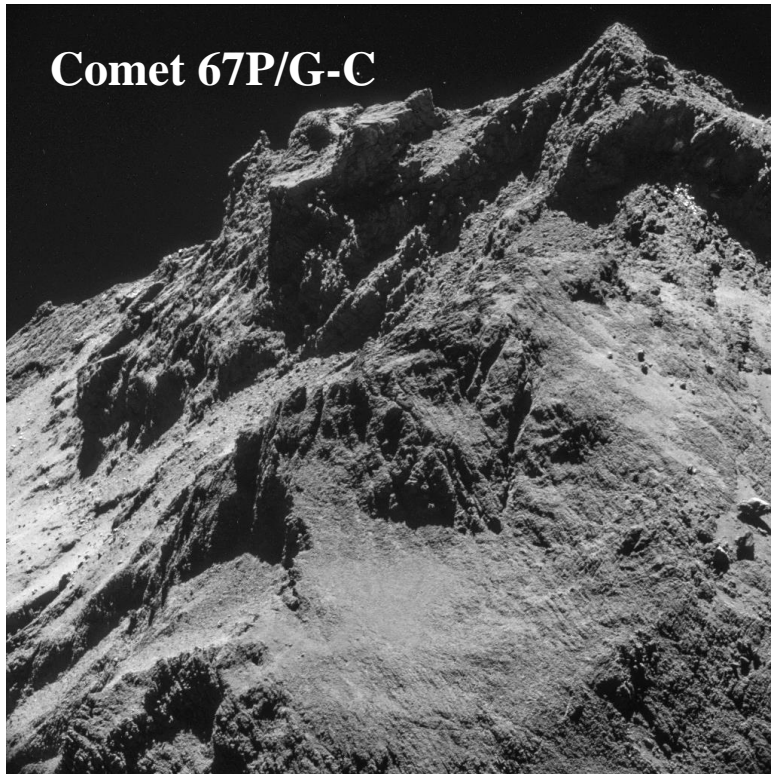
Breakdown of material from diurnal, thermally induced stresses caused by expansion and contraction of material.

Itokawa

Eros

Our Moon

What stresses are induced on these surfaces?
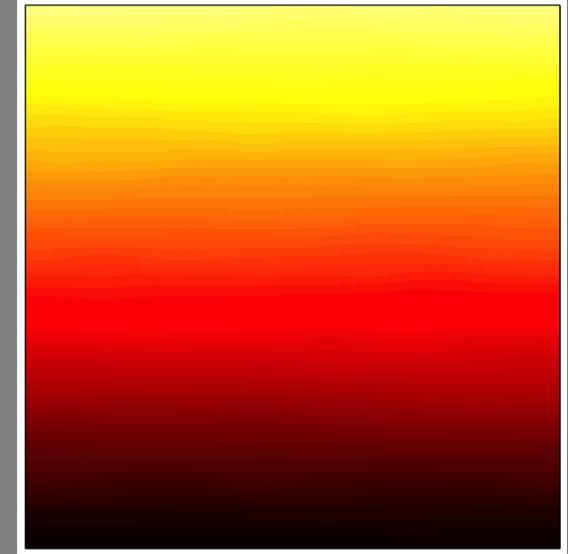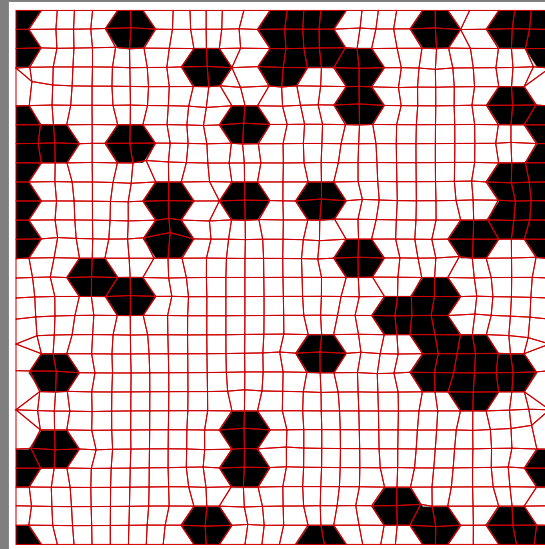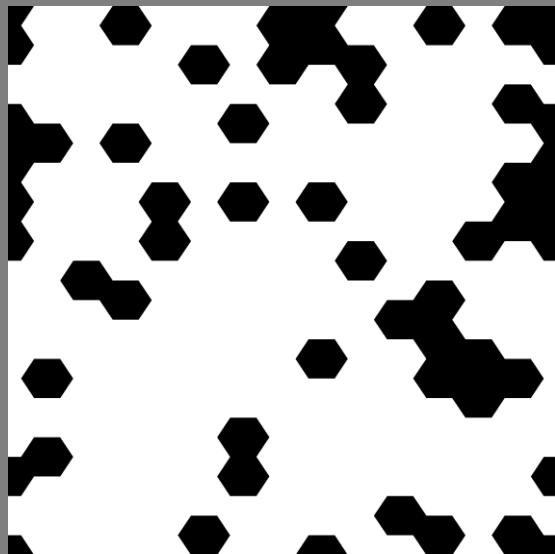What are the implications for surface evolution?

Thermally Induced Ice Breakdown?

How does the thermomechanical behavior of ice and ice-rock mixtures differ from that of rock?

Comet 67P/G-C

Ceres

2D Modeling of Microstructures (OOF2)

Microstructure Properties **+** Q(t) → Heat Equation

Displacement Equation → Stress
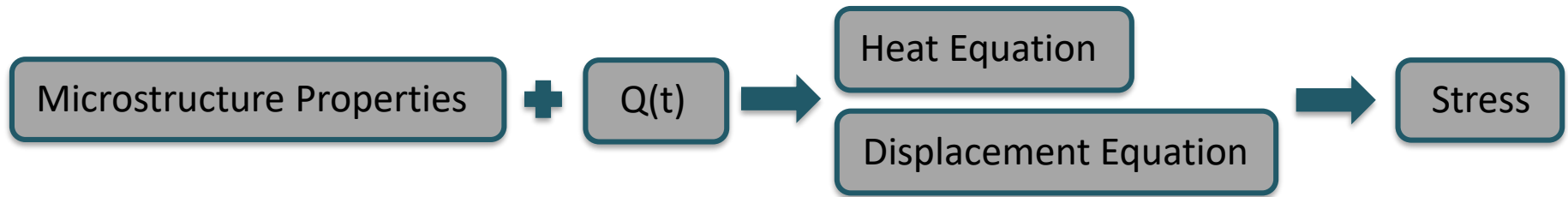
Heat Flux In ↓

Heat Flux Out ↓

2D Modeling of Microstructures (OOF2)

Time dependent fluxes from a 1-D heat conduction model.

$$\frac{dT}{dt} = \left(\frac{1}{\rho c_p}\right) \nabla \cdot (k\nabla T)$$

Solar Flux

IR

dT/dz

Heat Flux In

Heat Flux Out

How does <u>rock</u> behave under thermal cycling?
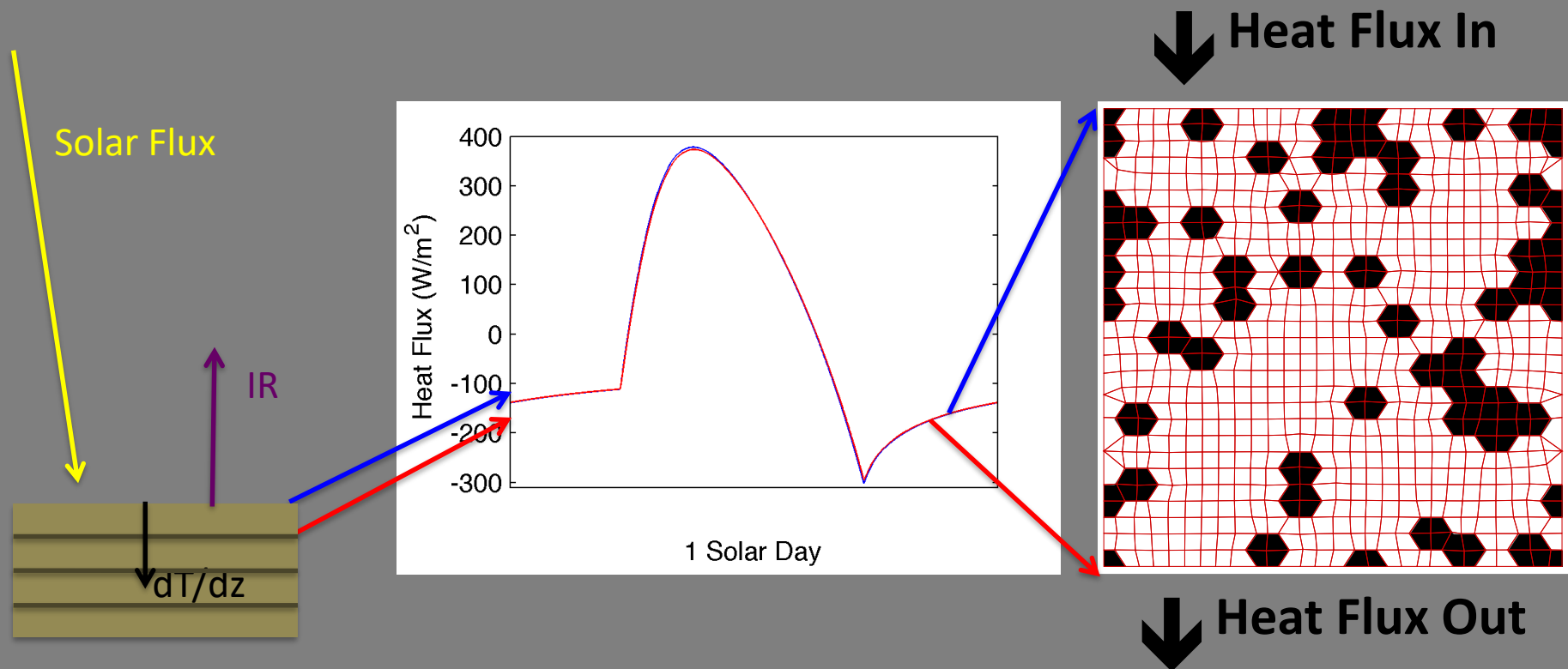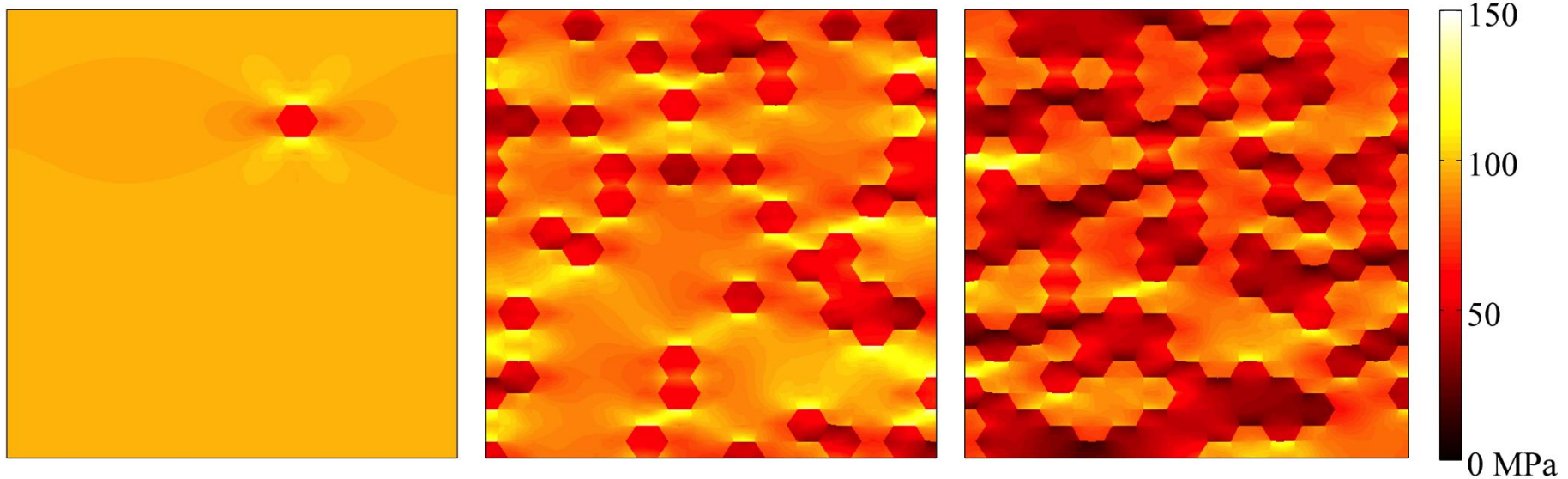
- Stresses concentrate at grain boundaries
- Stresses are controlled by mineral properties
- Breakdown is controlled by grain distribution

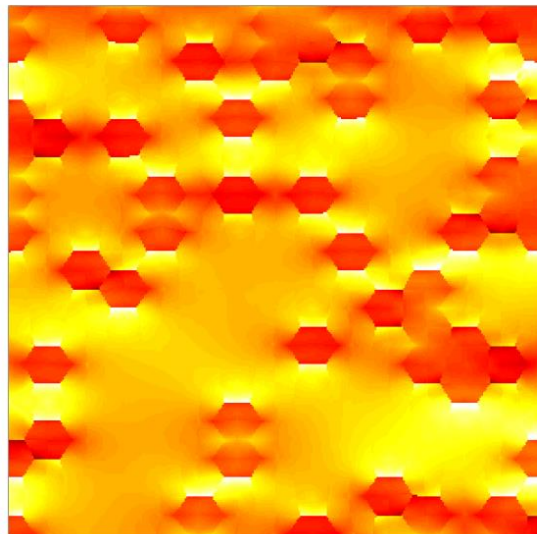Peak tensile stress in a lunar basalt microstructure.

Molaro et. al. (2015), **Grain-scale thermoelastic stresses and spatiotemporal temperature gradients on airless bodies, implications for rock breakdown.** *JGR Planets* 120, 255-277.

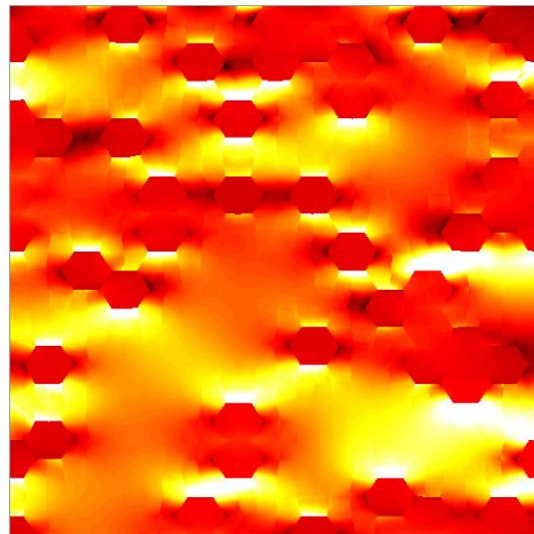# How does <u>ice</u> behave under thermal cycling?

Test Case: Ceres

- Stresses concentrate in grains with higher expansion coeff.
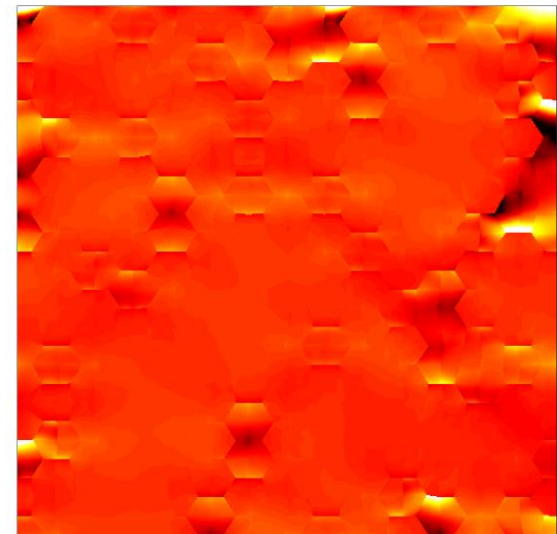- Stresses in mixtures are higher than in rock, but concentrated in fewer locations

Rock	Mostly Rock (25% Ice)	Mostly Ice (25% Rock)
Peak Stress = 5.8 MPa	11.25 MPa	8.6 MPa

- Mixtures experience both compressional and tensile stresses due to strong difference in expansion coefficient

Rock   Mostly Rock (25% Ice)   Mostly Ice (25% Rock)
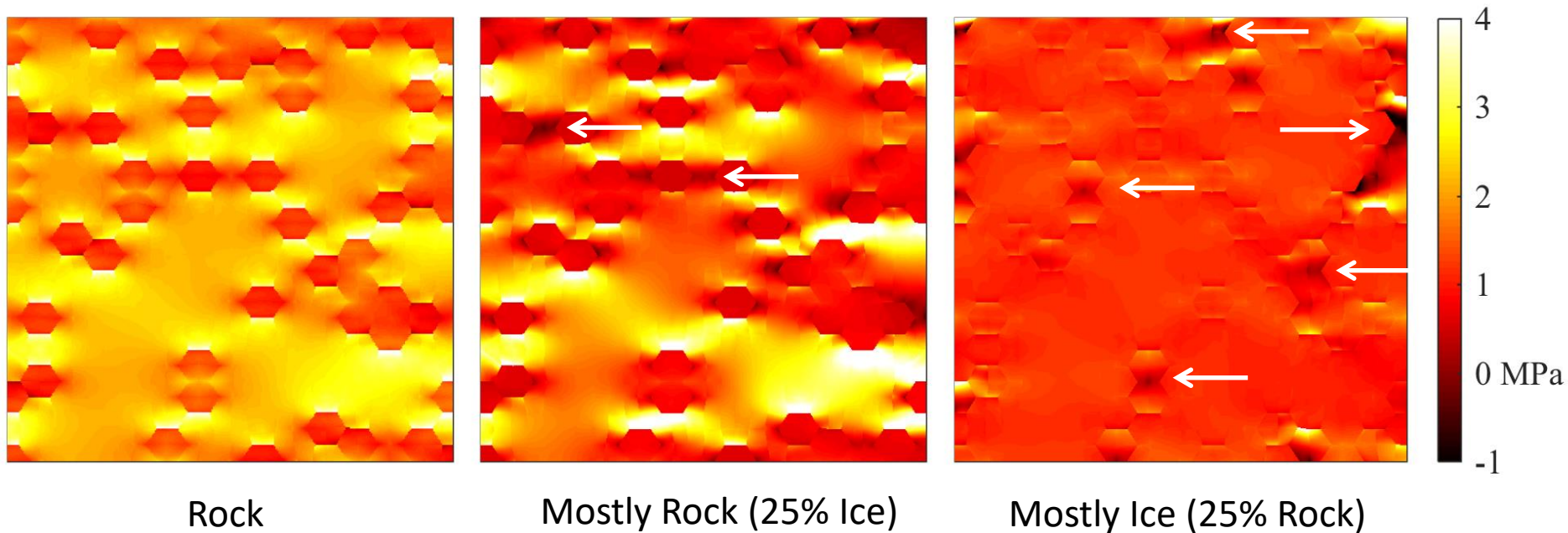
Rock and ice-rock mixtures behave differently!
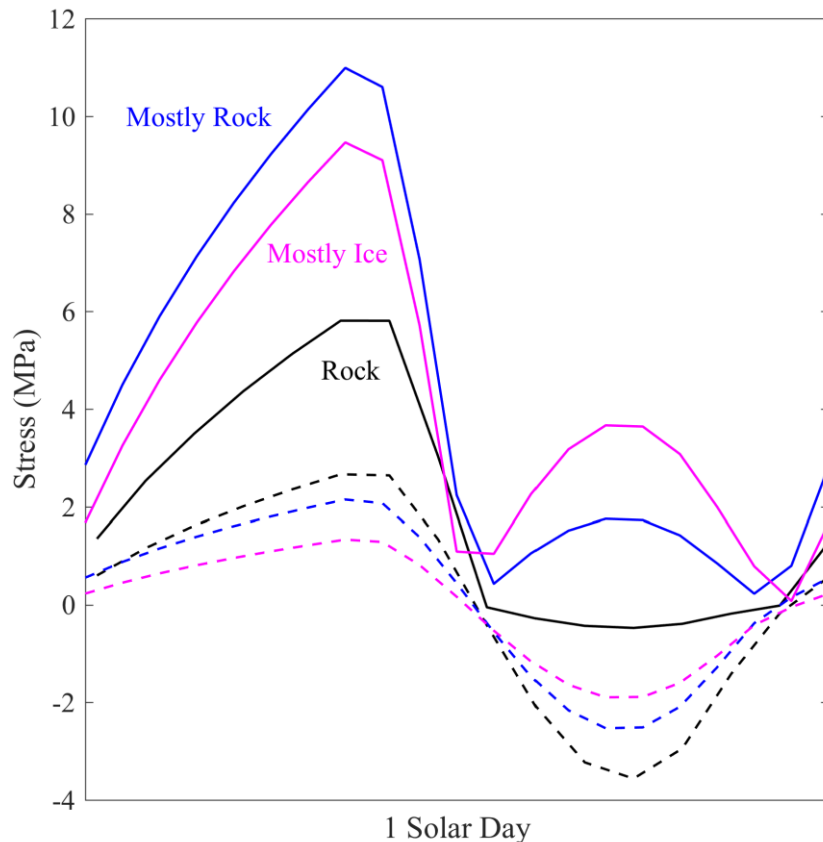
This may have important implications for the way that fractures develop on objects such as Ceres and comet 67P.

Comet 67P at perihelion is closer to the sun, and experiences ~30-50 MPa depending on the ice-rock ratio.

Peak (solid) and average (dotted) tensile stresses in rock and ice-rock mixtures.

Conclusions

- Rock and ice-rock mixtures behave differently under thermal cycling.

- Stresses concentrate in grains with a higher expansion coefficient.

- Stresses in mixtures are higher than in rock, but concentrated in fewer locations
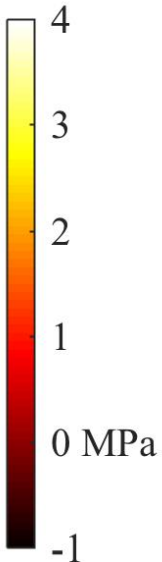 - *This suggests that fewer, larger scale fractures may develop in mixtures than in rock.*

- Mixtures experience both compressional and tensile stress
  - *This has interesting implications for crack propagation and annealing.*